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Developments in low-cost laser detection: wide field of view implementation and direction determination

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ABSTRACT

The availability of low cost but relatively high power laser pointers (hundreds of mW) has led to misuse with potentially dangerous consequences, such as dazzling aircraft which has raised concerns about aircraft safety. A low cost laser detection system based on coherence detection has been developed and is able to detect weak, continuous laser sources even against bright background light.[1] In this paper, we introduce the use of a cone mirror to extend the horizontal field of view of the detector (originally at 3°) to 360° to detect incoming beams from different directions. With the additional use of a camera in the system, we also determine the direction of the incoming laser beam. Finally, the sensitivity between the original system and the cone mirror system are compared: the new system showed promising results with a sensitivity below 100nW.

Keywords: Laser warning systems, coherence discrimination, cone mirror, laser direction, field of view

1. INTRODUCTION

With the creation and the development of lasers in the early 1960s, the question of how to detect this technology has naturally followed. In the military, this question has raised even more interest since lasers have been used for decades for targeting, range finding, designation, and missile control.[2] Laser Warning Receivers (LWRs) have been developed to identify the nature of the laser threats as well as the direction of irradiation. Once this information is known, the appropriate countermeasure such as smoke screens can be taken. The LWR systems are meant to be used on land, sea or vehicles but can also be used on buildings and air platforms. It is important to get a wide field of view from those devices as it will allow a better coverage on the battlefield.

Most often, LWRs are composed of three units: an optical unit, a detection unit, and a processing unit.[3] The field of view of a LWR depends on the composition of the optical and/or detection unit but can be extended with additional optical components. For example, imaging laser detection systems (ILDS) are usually composed of a fish-eye lens and CCD or CMOS camera devices[4] and can reach 180° of field of view. Oftentimes several ILDS units needs to be combined together to reach a 360° full azimuthal coverage.[5] However, this is not a cost-effective system. Interferometer based detection systems are another type of LWRs and are based on coherence detection, their field of view will be restricted by the size of the interferometer aperture. A Fabry-Prot based LWR has already achieved a horizontal field of view of 160°[6] while a static Michelson interferometer associated with an optical antenna has demonstrated a 45° horizontal coverage.[7] Sometimes, the field of view needs to be reduced to 120° in order to increase sensitivity in the system.[8] Diffraction gratings can also be used as part of detection systems, and typically relies on the use of a CCD camera. In 2014 , a fish eye lens was combined with a sinusoidal amplitude grating and the system is able to achieve a 160 ° field of view.[9]

The laser detection system used for this work is composed of a Mach-Zehnder interferometer, combined with a balanced detector composed of two photodiodes at the outputs of the interferometer and a data acquisition unit (USB-6341 Multifunction I/O Device) used to digitize and send the data to a computer.[1] The field of view of this system has been measured and is equal to ±3°, this value being due to the detector size (3mm long). The aim of this work was to expand the field of view thereby making the device more practical. In addition to the field of view, the incoming beam direction has been studied as it is essential to determine the origin of the threats.

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2. CONFIGURATION OF THE LASER DETECTION SYSTEM - COHERENCE MODULATION

2.1 Principle of the Original System

The laser detection system works by detecting light sources that have a significant coherence length rather than the conventional detection of enhanced brightness. For this to work, the path difference between the two Mach Zehnder arms are set to be longer than the coherence length of the background light, which is the case with distances over few micrometers long. A piezo-mounted mirror replaces one of the two reflective mirrors of the original Mach-Zehnder interferometer to modulate the path length in one arm. Thus the path difference combined with the modulating element cause the output signal to be modulated at a known frequency only if the input light has a longer coherence length than the path difference. In other words, detecting a modulating signal will indicate the presence of laser light in the system. A schematic representation of the detection system is shown in Fig. 1.

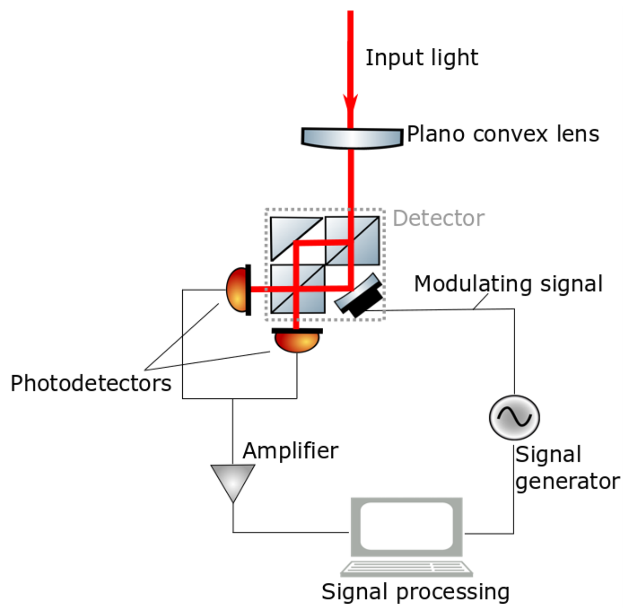


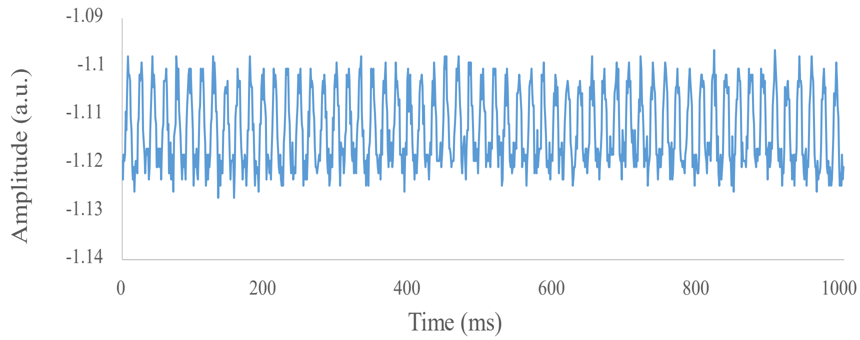
Figure 1: Configuration of the Mach-Zehnder laser detection system

The plano-convex lens (focal length f=7.5cm) helps to focus the laser beam on the two photodetectors. The beam splitters and the mirrors are 1cm long. The total optical path length from the focusing lens to the photodetectors is equal to 7.5 cm and this limits the field of view. The photodiodes are Si type and have a wavelength detection range from 350nm to 1100nm. For this experiment, we used a 635nm laser diode and the piezo mirror is modulated at a frequency of 600Hz and an amplitude of 2.7V.

To detect modulating signals at the output, the output voltage was sampled and a Fourier transform analysis is made: peaks in the Fourier transform at the modulation frequency (and its harmonics) are evidence of coherent input. A rolling average spectrum was generated by summing consecutive frequency spectra. The graph in Fig. 2 gives an example of a signal modulated at 1200Hz detected by the two photodiodes and the Fourier transform applied to the signal where the first and second harmonics are visible.

2.2 Implementation of the Wide Field of View

A Mach-Zehnder interferometer has the advantage of two distinct outputs, which implies that the two outputs can be used for two different applications at the same time. In this work, one of the outputs will be used to measure the intensity of the modulating signal via a photodiode while the second output will be used to determine the direction of the beam. A wide field of view will be achieved by using a cone mirror. A cone mirror



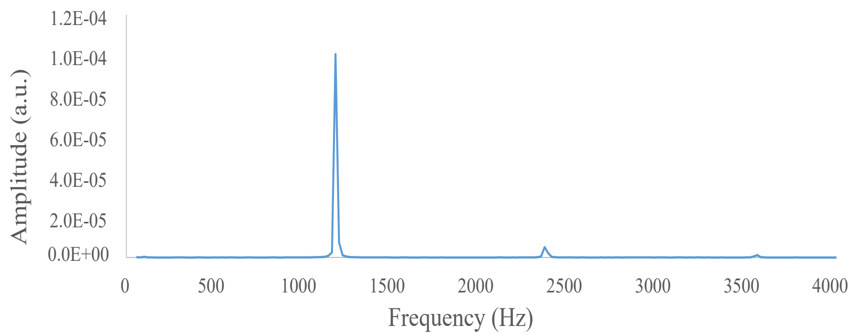


Figure 2: Example of an output signal modulated at 1200 Hz received by the photodiodes and its Fourier transform

is composed of a cylindrical base and a cone top. The top has a coating allowing reflection of a good percentage of the light towards the direction perpendicular to the input light as shown in Fig. 3. The cone mirror used in the experiment has a diameter of 1cm and a total length of 1.5cm and reflects at least 80% of the light.

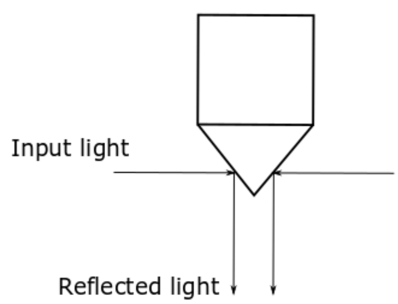


Figure 3: Cone mirror principle

This element is positioned to direct light into the interferometer. A camera looking through the interferometer at one of the output ports is focused on the cone mirror. Capturing an image of the cone mirror allows the direction of the laser input to be observed. A laser was shone into the system at various angles separated by 45° angles. The amplitude of the first harmonic and a camera image were recorded in each case. The set-up of our experiment with the cone mirror is shown in Fig. 4 and the 0° angle was set as illustrated.

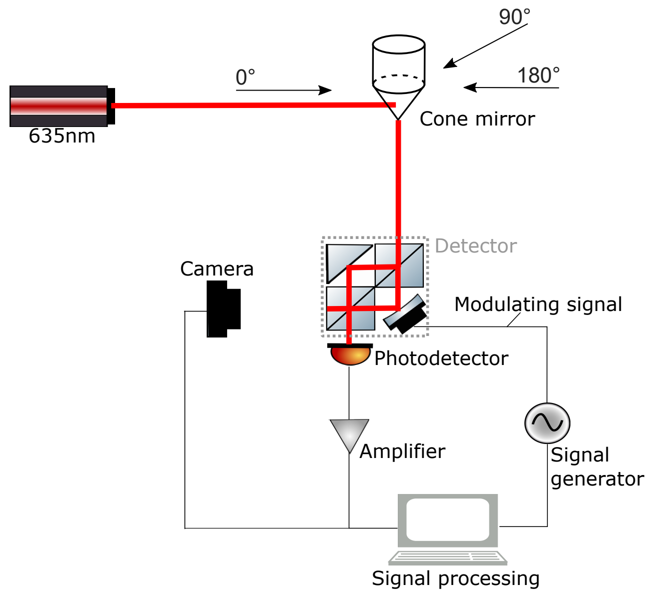


Figure 4: Configuration of the laser detection system with the cone mirror

3. RESULTS

3.1 Determination of the Direction of Irradiation

Captured images of the cone mirror when the laser was shone from 0° and 45° are shown in Fig. 5. The reflected beam is visible on the cone mirror; from these captures the direction is easily determined.

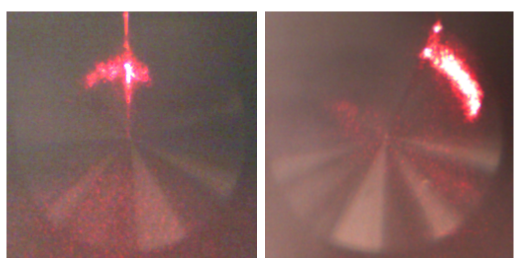


Figure 5: Captured images of the cone mirror when the laser is at 0° and 45°.

All the data of the first harmonic amplitude and of captures of the cone mirror at different angles are combined in the graph of Fig. 6. These results show that the laser is detected as a modulating input at every given angle. The measured amplitudes of the FFTs are very good and the direction of the laser beam can be determined from the camera.

3.2 Comparison of Input and Output Power for Original and Cone Mirror Systems

It is then interesting to look at the difference between the laser power before the laser beam entered the detector (measuring the power of the laser beam itself) and the laser power after it left through the last beam splitter (measuring the power at one of the two outputs) to know the attenuation of the light through the two different detection systems. In Fig. 7, the input/output power ratio for the original system and for the cone mirror system are shown.

For the original system, the transmission efficiency is 37% while for the wide field of view system, the transmission efficiency is 2.5%. For the original system, 50% efficiency was to be expected as only one of the two

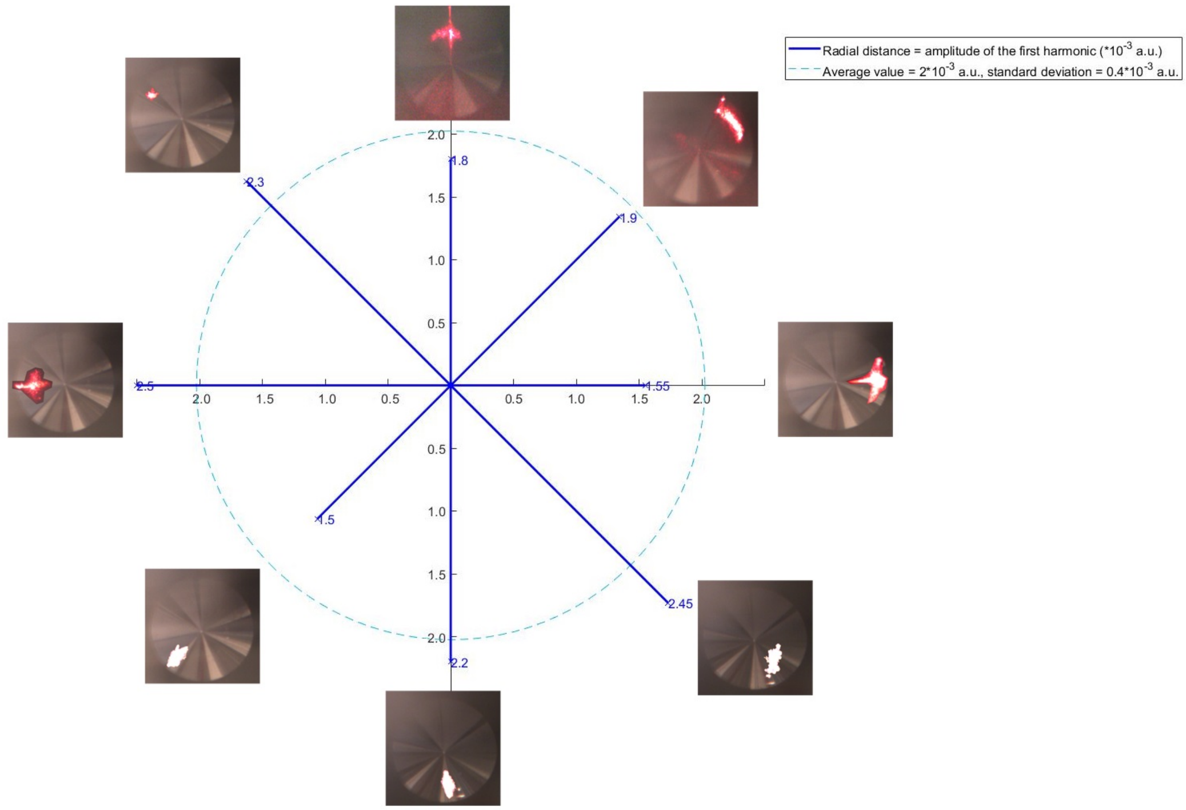


Figure 6: Combined data of experiment results on cone mirror

output ports is used in the measurement. The efficiency loss is due to the optics. In the cone mirror system, the additional losses comes from the reflected beam, which was widely distributed by the cone mirror and only a part of the laser light would reach the detector input.

3.3 Comparison of Sensitivity for Original and Cone Mirror Systems

In this part, the sensitivity of the system has been measured. It corresponds at the minimum laser power we need to distinguish the signal from the noise level. The sensitivity measurements have been done by measuring the Signal to Noise ratio (S/N) for different laser powers. The intensity of the laser diode is attenuated by using Neutral-Density filters and a power meter is used to measure the new laser input power level (values from 100μW to 10nW). For each laser power level, the signal to noise ratio is calculated by measuring the amplitude of the first harmonic of the signal FFT and by comparing it to the noise level. The results are plotted in Fig. 8. If the ultimate sensitivity is defined to be equal at the power when S/N=1, then the system is able to detect a signal down to around 70nW for the cone mirror system. These results are quite interesting, knowing that without a cone mirror (original system) the ultimate sensitivity was around 2nW.

3.4 Verification of Laser Detection System

To demonstrate that the cone mirror system detects only coherent sources, an LED and a laser were both directed towards the cone mirror. Both were at similar wavelength (635 nm) and can be seen on the camera image in Fig. 9. The LED appears significantly brighter on the camera image; however, no change in the amplitude of the first harmonic was seen when the LED was turned on and off. As expected the LED contributes nothing to the modulation signal.

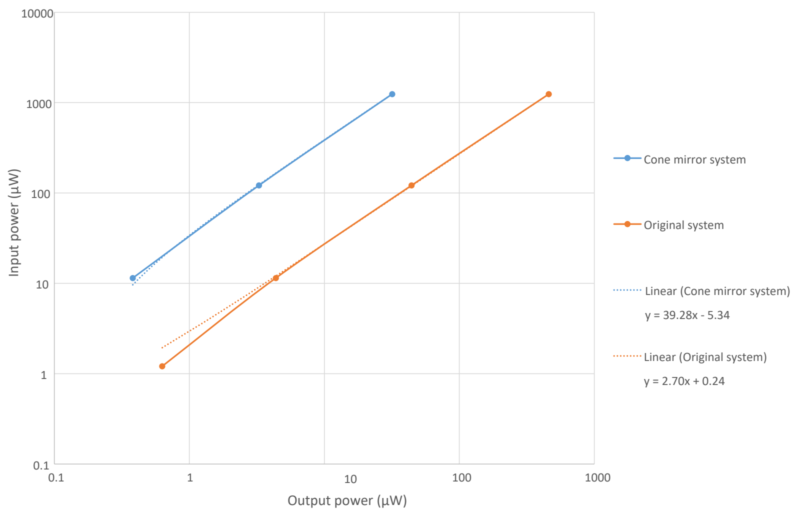


Figure 7: Comparison of input and output power for the cone mirror and the original systems

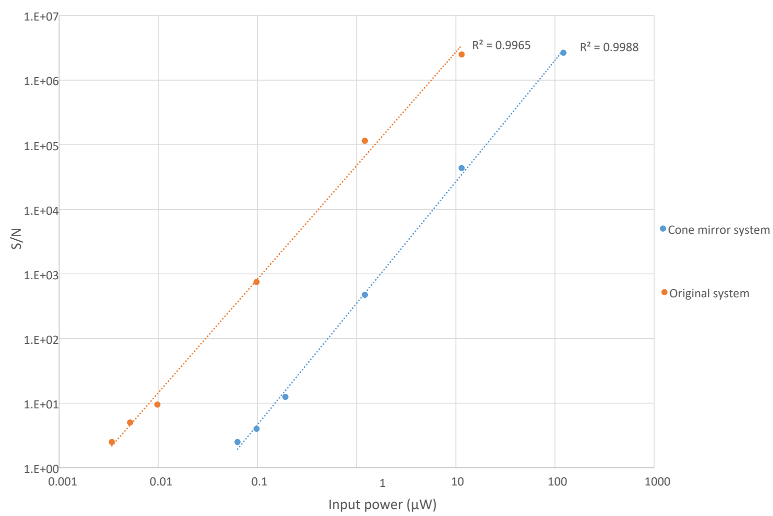


Figure 8: Comparison of sensitivity for the cone mirror and the original systems

4. CONCLUSION

With a cone mirror input, a CW laser is identified as a modulating input for a range of input angles which demonstrates a 360° field of azimuthal detection. Images captured by the camera show the position of the laser source on the cone mirror from which the source direction can be inferred. Using only one output of the Mach-Zehnder interferometer with a photodiode is enough to detect a laser signal with a large amplitude. Moreover, an LED is not detected by our detector showing the ability to discriminate lasers from non laser sources. So this detection system based on interferometry has been shown to be reliable in detecting the presence of a CW laser and to find the direction of the beam. This system has a high sensitivity and a wide spectral range (in this case the photodiode has a spectral range from 350nm to 1100nm) and the spectral range can easily be extended to infrared with the adapted optical sensors. The acquisition time of the detector is less than one second and it depends on the source intensity. Futhermore, the determination of the wavelength is possible if we use the piezo mirror modulation.[1]

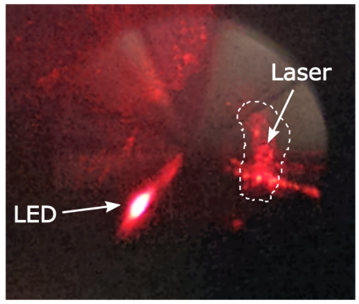


Figure 9: Captures of the LED and the laser lights on the cone mirror.

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